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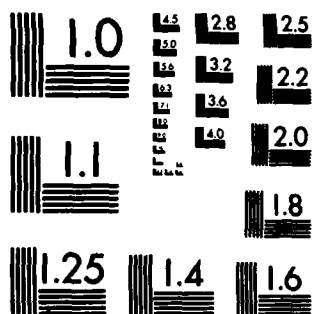
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OFFICE OF NAVAL RESEARCH

Contract #N00014-77C-0246

Task No. NR 205-028

ANNUAL REPORT NO. 5

The Use of Genetic Mechanisms and Behavioral Characteristics to
Control Natural Populations of the German Cockroach

by

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March 1983

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This research was supported in part by the Office of Naval Research,
Microbiology Program, Naval Biology Project under Contract N00014-77C-0246.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
	40-4125	874
4. TITLE (and Subtitle) The Use of Genetic Mechanisms and Behavioral Characteristics to Control Natural Populations of the German Cockroach		5. TYPE OF REPORT & PERIOD COVERED
7. AUTHOR(s) Mary H. Ross Donald G. Cochran		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Virginia Polytechnic Inst. & State University Blacksburg, VA 24061		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research 800 N. Quincy Street Arlington, VA 22217		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE
		13. NUMBER OF PAGES
		15. SECURITY CLASS. (of this report)
		16a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Genetic control Cockroach behavior <u>Blattella germanica</u>		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The summer work on an inactive ship made it possible to study population growth, behavior, and response to an insecticide treatment of German cockroaches under non-laboratory conditions. Complementary laboratory ^{Study} experiments support and provide some measure of understanding of the "field" observations. Both types of study have revealed differences in behavior according to age class, sex, and reproductive stage of adult females. Major features of these findings are summarized below.		

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Small nymphs (instars 1 and 2) aggregate intensely. They rarely move far from their harborage. They are generally under-represented in traps near infested harborages. Large numbers of small nymphs outside-of-harborage is a sign of stress. They predominated in traps sampling movement that followed removal of food and water and also those sampling large groups where harborages had apparently become over-crowded. They seem to be highly sensitive to residual insecticides. Large numbers died when egg cases were aborted and hatched on a treated surface. Older nymphs seem to be the most mobile part of the population. Their migration is a major mechanism whereby small groups adjust to limited harborage. Dispersal of this group either prior to or as a response to treatment resulted in less kill than seen in other age classes.

Adult males were characterized by random within-harborage distribution. They showed little or no response to chemical stimuli that promoted aggregation or that had repellent effects (presumably aggregation pheromone and repellent associated with high female density). They showed least survivorship of all age classes in a treatment aimed at partial kill.

Adult females show complex behaviors. They are producers of chemical stimuli that affect within-harborage distribution and that may trigger away-from-harborage movement. Their own survival and that of the species is enhanced by infrequent need to forage for water or food while carrying egg cases and by an apparently highly developed ability to locate water/food when entering a new area. A repellent associated with high densities of non-egg bearing females may act as a sensing mechanism to ensure adequate space for future hatch. Possibly this actively promotes the migration of mid-late stage nymphs noted above and underlies fluctuating densities in traps sampling small groups that had adjusted to limited harborage. Behaviors related to cyclic food-water consumption caused skewed sex ratios in trap catch even though nearby groups had 1:1 sex ratios. Widely dispersed females that moved as a result of treatment not only found water and food sources, but their presence was implicated in the successful formation of the nuclei of new "hot spots". Their immediate ability to add to the population was severely reduced by loss of egg cases during treatment, but this was temporary. Female behavior patterns in general suggest the evolution of reproductive and related behavioral strategies that make B. germanica a successful species in its chosen environment.

The shipboard studies showed that infested harborages tended to remain inhabited even if space was limited or food/water removed to a more distant location. Large numbers moved back into a favored harborage following treatment, yet newly infested sites in the general area were not completely abandoned. Tiny new infestations in distant areas also remained. They take on importance in view of the 1981 experiment. Movement was primarily from small to large groups, contrary to expectations. Small groups served as feeders of the higher-density groups. They are of far greater importance to effective control than is generally realized.

The research conducted during the past year is a continuation of studies designed to enhance our understanding of population behavior and dynamics of the German cockroach, Blattella germanica (L.). It includes both laboratory and "field" experiments on an inactive ship. Findings that we feel are of most significance are summarized below according to specific objectives. Objective 1 is omitted because it was completed earlier (sterile male experiment; Ross et al. 1981).

Objective 2 - Behavior within harborages

A laboratory study on within-harborage group behavior was completed as part of the M.S. thesis research of Brian Bret, a graduate student supported by this Contract (M.S. in June, 1982). A manuscript reporting the results has been submitted for publication. They show that the spatial distribution of a mixed aged group was affected by the reproductive state and density of adult females. In groups with egg case bearing females (gravid), aggregation intensified with increased female density. This included aggregation within and between the various age classes, except that adult males tended to be distributed randomly. In contrast, aggregation decreased with increased female density in groups with non-egg case bearing females. Females are apparently a motivating force in determining within-harborage distribution and, quite possibly, away-from-harborage dispersal when harborages become overcrowded (see Obj. 3). The results suggest that an aggregation pheromone, similarly to the better-known female sex pheromone, may be produced cyclically. Also implicated is the production of a repellent that not only appears to be associated with high density but may vary according to female reproductive state. Plans for continued research under this Contract include studies of the production of and response of different sex/age classes to these chemical stimuli.

Objective 3 - Cockroach population behavior

a. Laboratory experiments.

Mr. Bret's thesis research also included an experiment on away-from-harborage movement. Three inter-connected aquaria were used (Fig. 1). Food, water and shelter were available in the 1st and 3rd aquaria. Mixed age groups were introduced into the 1st aquarium, held sufficiently long for formation of a within-shelter group, then allowed to disperse freely. Contents of the 3 aquaria were censused at the end of 1 wk. The results showed differences according to age class. Table 1 summarizes experiments that included varying densities of adult females. Table 2 shows the data according to female density. The results correlate well with behavior as expected from the within-harborage aggregation experiment and as seen in the 1981 "field" experiment. In short, early instars did not move far from their harborage. This behavior showed no alteration with changes of female density. Comparatively high dispersal of mid instars



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corresponded to shipboard data showing away-from-harbor movement of mid-late instars. A tendency towards less movement of mid instars and adults into the more distant aquarium with increased female density supports density effects seen in the first experiment. Most of the females either started with or formed egg cases during the course of the experiment, i.e., correspondence to high aggregation with increased density of gravid females. We suspect this phenomena is partially responsible for fluctuating catch in the "field" experiment, although away-from-harbor movement was the major factor.

Fig. 2 shows limited comparisons between dispersal of females that did not form egg cases and those that formed egg cases in the course of the experiment. A trend towards less dispersal from aquarium 1 is apparent among the egg case-bearing females with an opposite tendency among those lacking egg cases.

The correspondence in behavioral patterns of within-harbor groups to away-from-harbor movement leaves little doubt the same chemical stimuli are involved.

b. "field" experiment. - A study of the growth and movement of groups established in known harborages on an inactive ship was conducted during the summer of 1981. A summary of the work was included in our last Annual Report (March 1982). The data are extensive. Three manuscripts are planned. The first is ready to submit for publication, and a copy will be forwarded under separate cover to our project officer, CDR Schultz. Points of interest are summarized below according to relevance to the interpretation of trapping data, population growth, movement, and particular behavioral patterns.

Interpretation of trapping data:

1. Peaks of highest trap density are reasonably good indicators of the location of infested harborages if an area is thoroughly sampled (40 traps in general area of galley in 1981 experiment).
2. Traps adjacent to infested harborages ("hot spots") give reasonably good indications of relative population densities. In our experiment, catch was generally 17-22% of the group in and around an infested harborage but, in two cases, catch was elevated where unusual numbers were moving into a new area.
3. Traps between infested harborages do not give reliable indications of the size of infestations in adjacent areas, and, indeed, may give little or no indication of their presence.
4. Catch in which early instars (small nymphs) predominate is a sign of population stress. This correlated with

evidence of overcrowding where high-density groups had developed and with removal of water and food from a position adjacent to an infested harborage to a more distant position.

5. Fluctuating catch as seen at 3 wk trap intervals in traps adjacent to infested harborages indicated restricted growth. In our data, the main limiting factor was harborage (one late trap set reflected food/water re-location).
6. In traps adjacent to a "hot spot", the ratio of adult males: mid-late instars was the best indicator of the age class composition of the resident group. Early instars were under-represented; adult females, over-represented (see "other observations").

Population growth:

1. Overall population growth as seen in the trapping data showed an exponential rate of increase (Fig. 3). This provides a standard that could be used to assess the amount of control achieved by a pest management program.
2. Growth of groups established where extensive harborage was available either (a) showed increases similar to the above or (b) sudden sharp increases that suggest additions from migrants that left other groups.
3. Adjustment of small groups to limited harborage was apparently by migration of mid-late instars. Thus growth was regulated by limiting the addition of new adult females and, as noted above, this mechanism was reflected by fluctuating catch.

Movement (additional data will be forthcoming from analysis of mutant markers planned for a 3rd manuscript):

1. A general categorization of movement was as follows: (1) least where traps were separated from harborages by open floor or walls ($\leq 1\%$); (2) comparatively minor where between-group movement was around margins of walls (ca. 2-5%); and (3) more extensive around the margins of infested harborages (roughly 5-10%).
2. Most between-group movement was apparently from small to large groups. Traps best placed to sample migrants showed fluctuating catch and predominance of mid-late instars; those adjacent to small groups in limited harborages also showed fluctuating catch and a failure of mid-late instars to increase adult numbers within the expected time span.

Other Observations:

1. Initial difficulty in establishing groups correlated with temperature below the "indifference zone". Eventual success occurred at warmer temperatures and when carton-type harborages were left onboard. We infer that dispersal was lessened by the presence of a harborage freshly impregnated with aggregation pheromone, but also suspect temperature-related differences in either response or production of aggregation pheromone. This needs investigation.
2. Once a group was established, there was a tendency for continued habitation, even if harborage was limited or water/food moved to a more distant location (also see Obj. 4).
3. High density groups apparently exerted an attraction for cockroaches entering the general area. Inference: attraction from high levels of aggregation pheromone. Response to aggregation pheromone is known to be olfactory.
4. Early instars seek concealment. Most were found in the carton-type harborages; they rarely occurred in traps in open situations; the proportion that moved past a source of water/food where a harborage was overcrowded was larger than that of other age classes.
5. In traps adjacent to infested harborages, the proportion of females caught was higher than that of other members of the group. Most of the females were non-gravid, as might be expected from the rapid rate of population increase. Such females have water/food requirements in excess of those of other members of the population (Cochran, unpubl.; see Obj. 5).

We call particular attention to #2 under "Movement". Groups that remained small throughout the summer served as "feeders" of large groups established in more favorable harborage situations. Dispersal following insecticide treatment could lead to the establishment of very small groups in new areas (see Obj. 4). Even if the new niche was not sufficiently favorable to promote population growth, such small groups could serve to re-infest and increase growth in favorable harborages once repellent effects of insecticides had dissipated.

Objective 4 - Insecticide-induced dispersal

A 2nd experiment was conducted on the same inactive ship that was used in 1981. A large population was established at a site known to offer extensive harborage and where one of the largest groups developed in the 1981 study (Fig. 4, site #2).

Trap sites were indicated as in the 1981 study, i.e., "main" sites as #'s 1-11 (water/food locations) and "peripheral" traps according to either association with main sites ("A", "B", or "C") or separation by open floor or walls (#'s 13-28). In addition, several new traps were located around and above #2 ("X" around #2 in Fig. 4).

A pre-treatment trapping caught cockroaches directly at #2 and in 2 of the 5 new peripheral traps (3 in 1; 2 in the other). Treatment was aimed at partial kill. Site #2 and the surrounding area was sprayed with 1% Bagon® (propoxur) in oil and then flushed with pyrethrins for 10-15 seconds. Dead and dying cockroaches were collected and counted. Immediate post-treatment trapping (1 night) was followed by 1 night trapping at weekly intervals. The experiment was terminated after 4 wks by a treatment aimed at complete kill. A major infestation at and around #2 was ringed with Baygon, sprayed with Baygon, and then with d-Phenothrin for flushing and additional kill. Small "hot spots" were searched out with d-Phenothrin with Baygon for kill if cockroaches were present. In the process of searching, areas around and including all water/food locations were at least sprayed with d-Phenothrin.

Table 3 shows data from the initial treatment; Table 4 summarized trapping data subsequent to both the initial and final treatments. Results as analyzed thus far include:

1. Higher kill of adult males than females in the first treatment (Table 3), but higher female survival was not evident in the final, heavier treatment. In the latter, 355. vs 486. were killed. The larger number of females is about as expected from higher female survival from the 1st treatment.
2. Many egg cases were aborted but others hatched on the treated surface at #2. This resulted in kill of over 800 newly-hatched nymphs.
3. Most dispersal was into the area around #2 (Table 4, "near" #2).
4. During the first 2 wks, cockroaches began to move back into the original site. The percentage of cockroaches caught at and around #2 that were directly at #2 was 13%, 64%, and 84% at 1 day, 1 wk, and 2 wks post-treatment, respectively.
5. Newly infested harborages around #2 remained inhabited following apparent cessation of the trend towards return to #2. Thus from wks 2-4 the percent caught directly at #2 apparently stabilized (84%, 82%, and 78% from wks 2-4, respectively).

6. Widespread initial dispersal was evident for a small portion of the population (Table 4, #'s 3-11 plus peripheral sites).
7. A few widely-dispersed cockroaches were found at 1 day post-treatment. They were in "peripheral" sites but by 1 wk it became evident some had found the water/food locations (#'s 3, 7, 8, 9 and 11).
8. At 1 wk, most of the above were either adult females or their newly hatched nymphs, suggesting adult females were particularly successful in locating water/food.
9. Small groups persisted where adult females were seen at the 1st wk, i.e., at #'s 3, 5, 6, 9 and 11. In contrast, no females were trapped or observed at #'s 7 and 8, sites where there was little or no evidence of an established group.
10. Proximity to water/food determined the location of new "hot spots" but, among such locations (main sites), choice seemed to be a matter of chance. Among the above, #'s 3 and 5 were known to be locations that favored population growth, in contrast to #'s 6, 9 and, to a lesser extent, #11 (1981 study). Food and water were available at #'s 4 and 10, but no cockroaches were found at either location.
11. Following the 2nd treatment, the largest number of survivors were again in the area around #2, but a few were found at #'s 8 and 10, two sites that had been lightly treated because no cockroaches were found in the "search and flush" procedures.

It is noteworthy that catch at #2 and in the surrounding traps was larger at 1 wk post-treatment than in subsequent weeks. Cockroaches were moving back to the original harborage(s). This correlates with data from the 1981 experiment showing movement increased the percent catch. The trapping data show little evidence of population growth, even though kill of egg case bearing females was partial. This is clearly the combined effect of aborted egg cases (no hatch) and death of nymphs that hatched from others that were dropped on the treated surface. Second egg cases were just starting to hatch at the conclusion of the experiment. Suppressive effects of the 1st treatment would soon have disappeared if the experiment had not been terminated. In contrast, it would clearly have taken much longer for growth to be re-established after the 2nd treatment (live trapping at 1 wk post-treatment of 206 vs 16 from 1st and 2nd treatments, respectively).

Objective 5 - Foraging behavior

Feeding and drinking behavior of adult females is also related to the reproductive cycle. Non-gravid females consume large amounts of both food and water while they are in the process of maturing the eggs for the next egg case. During this period they feed and drink on a daily basis, and obviously must forage frequently to find these resources. Both feeding and drinking drop off markedly as soon as the egg case is formed. While carrying their oothecae, females feed and drink intermittantly and sparingly. This greatly relieves the need for frequent foraging. Basic control mechanisms involved here may be related to those responsible for cyclic pheromone and/or hormone production. These and other aspects of the physiology and behavior of adult females are areas we would like to explore further, especially since they appear to have very real implications for pest management in B. germanica.

Publications of research supported in part by this Contract

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- Cochran, D. G. 1983. Food and water consumption during the reproductive cycle of female German cockroaches. *Ent. exp. Appl.*
- Bret, B. L. and M. H. Ross. 1983. The influence of adult females on within-harborage group formation of Blattella germanica. *Ann. Entomol. Soc. Amer.*

Presentations

Two invited talks were given in which research conducted under this Contract was included. One was in a cockroach symposium at the Eastern Branch meeting of the Entomological Society of America (Bret and Ross). The other was in a symposium sponsored by Whitmire Research Institute (Ross).

In addition, four papers were presented. These were at the meetings of the Va. Acad. Sci. (Bret and Ross), Eastern Branch, ESA (Cochran), and national meeting of the ESA in Toronto (Bret and Ross) (Cochran).

Acknowledgements

We again express a special debt of gratitude to those who cooperated in our continued summer work on the inactive ship at Portsmouth. LCDR McCroddan has served as our liason officer and he and those under his direction have greatly enhanced the successful completion of the experiment. We thank Captain H. J. Candela, Navy Environmental and Preventive Medicine Unit #2, for his cooperation in this endeavor. We also acknowledge gratefully the fine cooperation we received at the Inactive Ship Maintenance Facility at Portsmouth.

Table 1. - Distribution of cockroaches within a system of three inter-connected aquaria at the end of one week.

Population Component	% in aquarium #1	% in aquarium #2	% in tubes	% in aquarium #3
Adult Females	74.0	14.7	7.7	13.5
Adult Males	74.7	2.5	3.8	19.0
Middle Instars	58.6	6.1	7.8	27.6
Early Instars	86.1	2.2	1.5	10.2
Total	70.4	4.5	6.0	19.1

Table 2. - Distribution of cockroaches within a system of three inter-connected aquaria at the end of one week according to female density. Most females either had egg cases at the start of the experiment or formed egg cases during the week.

Female Density	Population Component	% in aquarium #1	% in aquarium #2	% in tubes	% in aquarium #3
4	Adult Females	45.8	0	18.3	35.4
	Adult Males	64.2	1.9	7.6	26.4
	Middle Instars	41.9	7.5	2.5	35.6
	Early Instars	85.6	1.1	1.1	12.2
	Total	57.0	4.0	10.8	28.2
3	Adult Females	61.7	17.0	5.3	16.0
	Adult Males	69.4	6.1	2.0	22.4
	Middle Instars	53.6	10.7	4.2	31.6
	Early Instars	86.5	4.8	1.9	6.7
	Total	65.5	10.1	3.6	20.7
16	Adult Females	85.4	0.4	6.4	7.7
	Adult Males	89.3	0	1.8	8.9
	Middle Instars	76.3	1.0	5.1	17.7
	Early Instars	86.2	0.5	1.2	12.5
	Total	82.7	0.5	4.7	12.1

Table 3. - Kill from initial treatment in 1982 "field" experiment (aimed at partial kill).

	Adult ♀	Adult ♂ (B1)	Mid- instars	Early instars
No. released	500 ^a	500	1500	1500
No. killed:				
fresh	137	229	171	188
debri at #2 ^b	<u>53</u>	<u>67</u>	<u>115</u>	<u>227</u>
total kill	190	296	286	415
% kill	38	61	19	28

^a All with egg cases approx. stage II-III at time of release, i.e., expected hatch at about 1 wk post-treatment.

^b Large numbers of both aborted and empty egg cases at #2, plus over 800 newly hatched nymphs that hatched and died on the treated surface.

Table 4. Distribution of cockroaches following treatment of population established at site #2.

Site ^a	Numbers trapped and/or observed at:							1 wk p.tr.
	1 day ^b p.tr.	1 wk p.tr.	2 wks p.tr.	3 wks p.tr.	4 wks p.tr.	(2nd tr.)	1 day p.tr.	
#1	0	0	1	2	2	--	0	1
#'s 1A-B	0	6	0					
#2	3	116	91	78	108	--	0	7
near #2	20	63	17	22	30		4	2
#3	0	4	3	8	9	--	4	0
#'s 3A-C	2	1	1	1	2	--	2	1
#4	0	0	0	0	0	--	0	0
#5	0	5	3	1	5	--	0	0
#5A	0	0	0	1	3	--	0	0
#6	0	1	22 ^c	0	2	--	0	0
#6A	0	0				--	0	0
#7	0	1	1	1	0	--	0	0
#'s 7A-B	2	0	0	1	0	--	0	0
#8	0	3	0	0	0	--	0	2
#'s 8A-C	0	0	0	0	0	--	0	1
#9	0	3	3	2	2	--	0	0
#9A	0	0	0	0	0	--	0	1
#10	0	0	0	0	0	--	0	0
#10 A-B	0	0	0	0	0	--	0	1
#11	0	3	7	2	3	--	0	1
#11A	0	0	1	0	0	--	0	0
#'s 13- 28	0	0	0	0	0	--	2	0
						(at #'s 19 & 20)		

^aSites #'s 1-11 supplied with water, food, harborage; sites within these areas indicated by "A", "B" or "C" on Fig. 4 except that new sites around #2 marked only by X (5 in surrounding area).

^bp tr. - post-treatment.

^cmostly hatch of 1 egg case (empty capsule and 21 small nymphs).

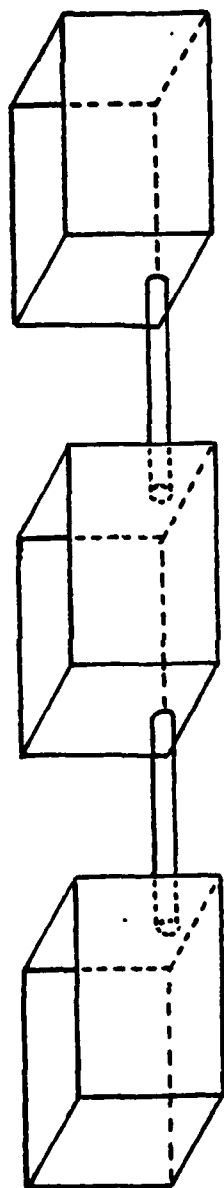


Figure 1.- System of three inter-connected aquaria used in a laboratory experiment on dispersion.

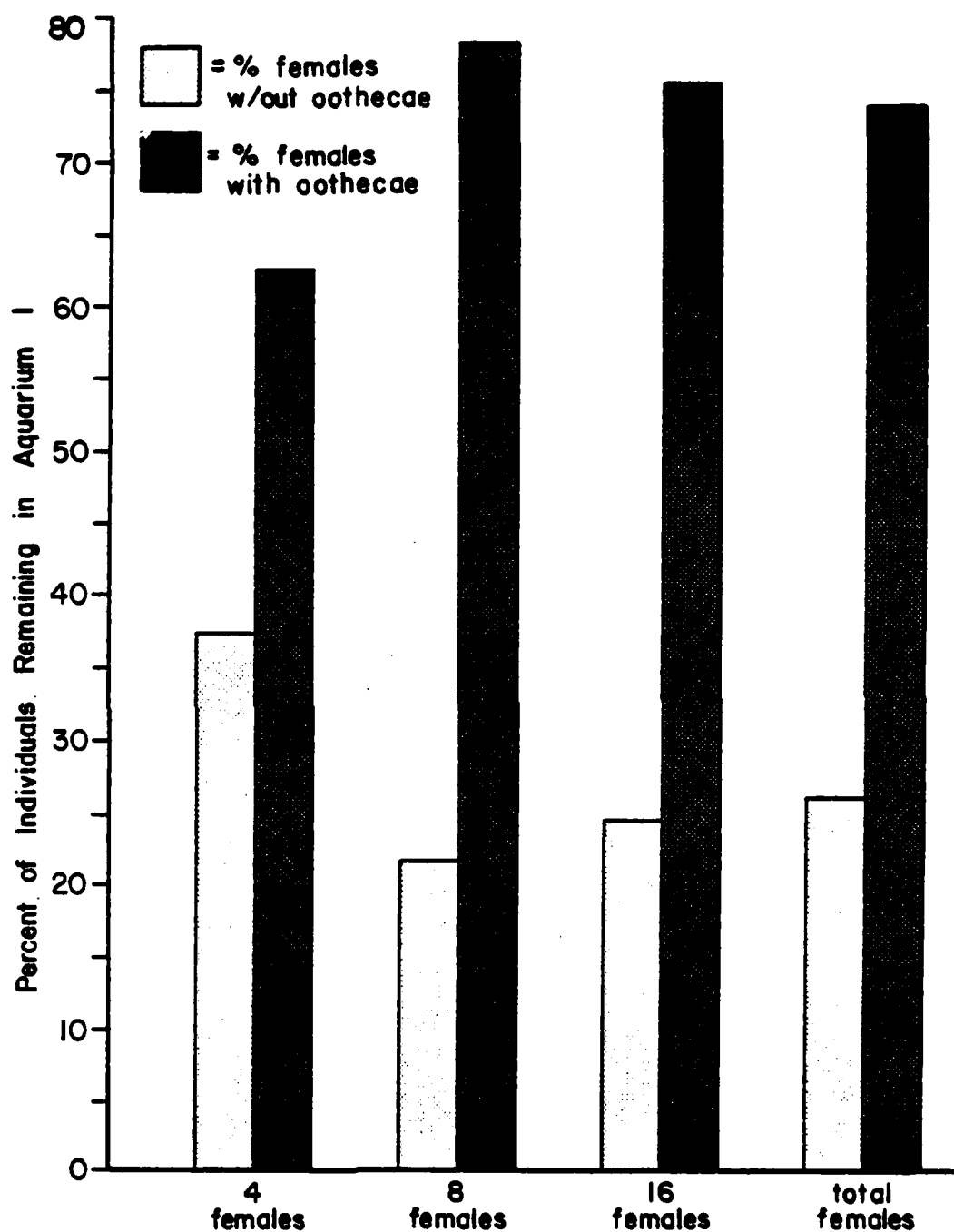


FIGURE 2 - COMPARISON OF EGG CASE AND NON-EGG CASE BEARING FEMALES THAT REMAINED IN AQUARIUM 1 IN EXPERIMENTS THAT STARTED WITH NON-EGG CASE BEARING FEMALES.

Figure 3.- Exponential growth as seen in the total trapping data from the 1981 experiment on an inactive ship. Unlimited water and food were available at 10-11 locations; harborage availability was extensive.

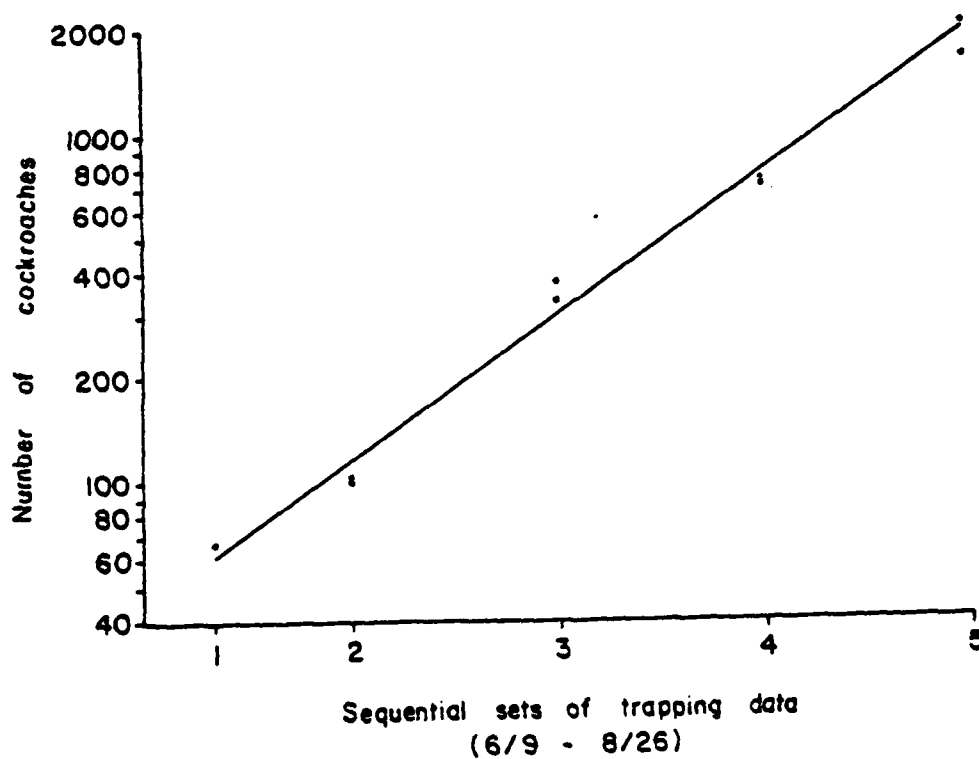


Figure 4.- Location of traps used in a study of wild-type growth and behavior (1981) and in a study of insecticide-induced dispersal (1982). The sites around #2 marked with "X" were added in the 1982 experiment.

